

1 TITLE OF THE INVENTION

2 VEHICLE SURROUNDINGS MONITORING APPARATUS

3

4 BACKGROUND OF THE INVENTION

5 1. Field of the invention

6 The present invention relates to a vehicle surroundings  
7 monitoring apparatus and more in particular to a vehicle  
8 surroundings monitoring apparatus suitable for detecting solid  
9 objects successively disposed along roads such as guardrails,  
10 side walls and the like.

11 2. Prior arts

12 With increased number of vehicles and with increased  
13 number of traffic accidents, the conception of Advanced Safety  
14 Vehicle (ASV) is becoming one of primary strategies in designing  
15 a vehicle. In particular, an ASV technology raises the  
16 intelligence level of a vehicle through the state of the art  
17 electronic technologies. In recent years, various safety devices  
18 such as issuing an alarm to inform a vehicle driver of a likelihood  
19 of collision, stopping a vehicle, decreasing or increasing the  
20 speed of the vehicle by detecting a vehicle traveling ahead or  
21 an obstacle through a television camera, a laser-beam radar or  
22 the like, have been proposed.

23 The applicant of the present invention, in Japanese  
24 Patent Application Laid-open No. Toku-Kai-Hei 5-265547, have  
25 already disclosed a technique in which images taken by two  
26 stereoscopic cameras are transformed into distance images, these  
27 distance images being divided into lattice-like small regions  
28 at a prescribed interval to detect solid objects for each small

1 region. Further, the applicant, in Japanese Patent Application  
2 Laid-open No. Toku-Kai-Hei 6-266828, have already proposed a  
3 technique wherein similarly data of solid objects per small  
4 region are extracted, these data being processed by a so called  
5 "Hough" transformation method to detect the solid objects such  
6 as side walls and guardrails aligned along roads.

7           However, according to these known arts, since the data  
8       of solid objects are processed by the "Hough" transformation  
9       method and the like, as a result, with respect to the solid objects  
10      provided along a curved road like guardrails, only their small  
11      portions located within a relatively short distance are  
12      recognized as straight lines, therefore it is much more difficult  
13      to recognize those objects in the distance.

## 15 SUMMARY OF THE INVENTION

16 The present invention is intended to obviate the  
17 aforesaid problem of the prior arts and it is an object of the  
18 present invention to provide a vehicle surroundings detecting  
19 apparatus capable of detecting a series of solid objects which  
20 constitute a boundary of a road as a wall surface even in case  
21 where the road is curved.

22 In order to achieve the object, the present invention  
23 comprises a wall surface detecting means for dividing positional  
24 data of solid objects into groups and based on the grouped  
25 positional data of the solid objects for detecting a wall surface  
26 formed along a boundary of a road, a wall surface model forming  
27 means for interconnecting a plurality of nodes and based on the  
28 interconnected nodes for forming a wall surface model to express

1 an outline of the side wall and a wall surface model correcting  
2 means based on the grouped positional data of the solid objects  
3 for correcting the wall surface model.

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5 BRIEF DESCRIPTION OF THE DRAWINGS

6 Fig. 1 is an overall view of a vehicle surroundings  
7 detecting apparatus mounted on a vehicle;

8 Fig. 2 is a schematic block diagram of a vehicle  
9 surroundings detecting apparatus according to the present  
10 invention;

11 Fig. 3 is a first flowchart showing a flow of control  
12 of a solid object/side wall group detecting process;

13 Fig. 4 is a second flowchart showing a flow of control  
14 of a solid object/side wall group detecting process;

15 Fig. 5 is a third flowchart showing a flow of control  
16 of a solid object/side wall group detecting process;

17 Fig. 6 is a flowchart showing a flow of control of a  
18 wall surface detecting process;

19 Fig. 7 is a first flowchart showing a flow of control  
20 of a wall surface position correcting process;

21 Fig. 8 is a second flowchart showing a flow of control  
22 of a wall surface position correcting process;

23 Fig. 9 is an explanatory view showing an example of  
24 images taken by cameras mounted on a vehicle;

25 Fig. 10 is an explanatory view showing an example of  
26 distance images shown in Fig. 9;

27 Fig. 11 is an explanatory view showing the position  
28 of solid objects detected per respective strips;

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1           Fig. 12 is an explanatory view showing the result of  
2 detection of side walls;

3           Fig. 13 is an explanatory view showing the result of  
4 detection of side walls in terms of the X-Z plane;

5           Fig. 14 is a schematic view showing a wall surface  
6 model;

7           Fig. 15 is an explanatory view showing the way of  
8 searching a wall surface pattern;

9           Fig. 16 is an explanatory view showing an example of  
10 a pattern of a weight coefficient;

11          Fig. 17 is an explanatory view showing the result of  
12 calculation of a degree of coincidence;

13          Fig. 18 is an explanatory view showing the connection  
14 of nodes;

15          Fig. 19 is an explanatory view showing the result of  
16 detection of wall surfaces; and

17          Fig. 20 is an explanatory view showing the result of  
18 detection of wall surfaces in terms of the X-Z plane.

19

20 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

21          Referring now to Fig. 1, reference numeral 1 denotes  
22 a vehicle on which a vehicle surroundings monitoring apparatus  
23 2 is mounted for imaging objects within a visible scope ahead  
24 of the vehicle and for recognizing the objects for monitoring.

25 The vehicle surroundings monitoring apparatus 2 comprises a  
26 stereoscopic optical system 10 for imaging objects from two  
27 different positions, an image processor 20 for processing images  
28 of these objects to obtain three-dimensional distance

1 distribution information, and a recognition/judgment computer  
2 30 for detecting three-dimensional positions of roads and solid  
3 objects at high speeds based on the distance information inputted  
4 from the image processor 20, for identifying a preceding vehicle  
5 or an obstacle based on the result of the detection and for judging  
6 whether or not an alarm should be issued to avoid a collision  
7 with the preceding vehicle or the obstacle.

8           The recognition/judgment computer 30 is connected with  
9 sensors such as a vehicle speed sensor 4, a steering angle sensor  
10 5 and the like in order to detect a present traveling condition  
11 of the vehicle and also it is connected with a display 9 provided  
12 at the front of a vehicle driver for informing hazard. Further,  
13 the computer 30 is connected with an external interface for  
14 example for controlling actuators (not shown) which operate so  
15 as automatically to avoid a collision with the obstacle or the  
16 vehicle traveling ahead.

17           The stereoscopic optical system 10 is composed of a  
18 pair of left and right CCD (Charge Coupled Device) cameras 10a,  
19 10b. A pair of stereoscopic images taken by the CCD cameras 10a,  
20 10b are processed in the image processor 20 according to the  
21 principle of triangulation to obtain three-dimensional distance  
22 distribution over an entire image.

23           The recognition/judgment computer 30 reads the  
24 distance distribution information from the image processor 20  
25 to detect three-dimensional positions with respect to the  
26 configuration of roads and solid objects such as vehicles and  
27 obstacles at high speeds and judges a possibility of collision  
28 or contact with these detected objects based on the traveling

1 condition detected by the vehicle speed sensor 4 and the steering  
2 angle sensor 5 of the self vehicle to inform the vehicle driver  
3 of the result of the judgment through the display 9.

4 Fig. 2 shows a constitution of the image processor 20  
5 and the recognition/judgment computer 30. The image processor  
6 20 comprises a distance detecting circuit 20a for producing  
7 distance distribution information and a distance image memory  
8 20b for memorizing this distance distribution information. More  
9 specifically, the distance detecting circuit 20a calculates a  
10 distance to a given object by selecting a small region imaging  
11 an identical portion of the object from the left and right  
12 stereoscopic images taken by the CCD cameras 10a, 10b,  
13 respectively and then obtaining a deviation between these two  
14 small regions and outputs in the form of three-dimensional  
15 distance distribution information.

16 Fig. 9 shows an example of either of images taken by  
17 the left and right CCD cameras 10a, 10b. When this image is  
18 processed by the distance detecting circuit 20a, the distance  
19 distribution information outputted from the distance detecting  
20 circuit 20a is expressed as a distance image as shown in Fig.  
21 10.

22 The example of the distance image shown in Fig. 10 has  
23 a picture size composed of 600 (laterally) x 200 (longitudinally)  
24 picture elements. The distance data are included in white dotted  
25 portions that correspond to the portions having a large difference  
26 of brightness between two adjacent picture elements aligned in  
27 the left and right direction respectively in the image shown in  
28 Fig. 9. Further, in this example, the distance detecting circuit

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1 20a treats the distance image as an image composed of 150  
2 (laterally) x 50 (longitudinally) blocks, i.e., 4 x 4 picture  
3 elements for one block or one small region. The calculation of  
4 distance is performed for each block of the left and right images.

5 The recognition/judgment computer 30 comprises a  
6 microprocessor 30a primarily for detecting the road configuration,  
7 a microprocessor 30b primarily for detecting solid objects based  
8 on the configuration of a road detected and a microprocessor 30c  
9 primarily for identifying a preceding vehicle or an obstacle based  
10 on the positional information of the detected solid objects and  
11 for judging a possibility of collision or contact with the  
12 preceding vehicle or the obstacle and these microprocessors 30a,  
13 30b, 30c are connected in parallel with each other through a system  
14 bus 31.

15 The system bus 31 is connected with an interface circuit  
16 32 to which the distance image is inputted from the distance image  
17 memory 20b, a ROM 33 for storing a control program, a RAM 34 for  
18 memorizing miscellaneous parameters produced during  
19 calculations, an output memory 35 for memorizing the result of  
20 processing, a display controller 30d for controlling the display  
21 9 and an I/O interface circuit 37 to which signals are inputted  
22 from the vehicle speed sensor 4 and the steering angle sensor  
23 5.

24 As shown in Fig. 9, the distance image has a coordinate  
25 system composed of a lateral axis i, a longitudinal axis j and  
26 a vertical axis dp with an origin of the coordinates placed at  
27 the left below corner of the distance image. The vertical axis  
28 dp indicates a distance to an object which corresponds to the

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1 deviation amount between blocks. Therefore, in the image  
2 processing computer 30, a point (i, j, dp) on the distance image  
3 is transformed into a coordinate system provided in the real space  
4 to perform processes such as recognition of the road configuration,  
5 detection of the position of solid objects and the like.

6 That is to say, with respect to the three-dimensional  
7 coordinate system fixed to a self vehicle in the real space,  
8 setting X axis on the right side with respect to the traveling  
9 direction of the self vehicle (vehicle 1), Y axis in the upward  
10 direction of the vehicle 1 and Z axis in the forward direction  
11 of the vehicle and placing an origin of the coordinates on the  
12 road surface underneath the center of two CCD cameras 10a, 10b,  
13 X-Z plane ( $Y = 0$ ) coincides with the road surface, if the road  
14 is flat. Accordingly, the point (i, j, dp) on the distance image  
15 can be transformed into a point (x, y, z) in the real space as  
16 follows:

$$17 \quad x = CD / 2 + z \cdot PW \cdot (i - IV) \quad \dots \quad (1)$$

$$18 \quad y = CH + z \cdot PW \cdot (j - JV) \quad \dots \quad (2)$$

$$19 \quad z = KS / dp \quad \dots \quad (3)$$

20 where CD is an interval between CCD cameras 10a, 10b; PW is an  
21 angle of visibility per picture element; CH is a height of CCD  
22 cameras when measured from the road surface; IV, JV are  
23 coordinates of an infinite point directly in front of the vehicle  
24 1 on the image; and KS is a distance coefficient ( $KS = CD / PW$ ).  
25

26 Rewriting the above equations (1), (2) and (3) as  
27 follows:

$$27 \quad i = (x - CD / 2) / (z \cdot PW) + IV \quad \dots \quad (4)$$

$$28 \quad j = (y - CH) / (z \cdot PW) + JV \quad \dots \quad (5)$$

1                    $dp = KS / z$                          .... (6)

2                   Next, processes in the recognition/judgment computer  
3                   30 will be described.

4                   In the microprocessor 30a, first, actual lane markers  
5                   of a road are extracted from three-dimensional positional  
6                   information contained in the distance image which is stored in  
7                   the distance image memory 20b and then the configuration of the  
8                   road is recognized by modifying parameters of a built-in road  
9                   model so as to agree with the actual road configuration.

10                  The road model described above is expressed by a  
11                  plurality of three-dimensional linear equations. That is, the  
12                  imaged left and right lane markers of the road on which the subject  
13                  vehicle is traveling are divided into a plurality of intervals  
14                  determined according to distance and the road model is formed  
15                  by a plurality of broken lines each of which is expressed for  
16                  every interval in the following three-dimensional linear  
17                  equations:

18                   $x = a \cdot z + b$                          .... (7)

19                   $y = c \cdot z + d$                          .... (8)

20                  where  $a$ ,  $b$  are parameters of a linear equation extended in the  
21                  horizontal direction in the coordinate system of the real space  
22                  and  $c$ ,  $d$  are parameters of a linear equation extended in the  
23                  vertical direction in the coordinate system of the real space.

24                  In the microprocessor 30b wherein the detection of  
25                  solid objects is processed, the distance image is divided into  
26                  lattice-like strips having a prescribed interval and data of  
27                  solid objects are extracted for every strip. Then, a histogram  
28                  is produced per each of these strips based on the data of solid

1 objects and the position on the X-Y plane of solid objects  
2 representing respective strips and the distance thereto are  
3 obtained from the histogram. Then, comparing the image  
4 successively from the left to the right, the images having close  
5 distances in the forward and backward direction (Z-axis  
6 direction) and the lateral direction (X-axis direction) are  
7 classified into the same group. Further, when the arrangement  
8 direction of the data is checked, the portion where the  
9 arrangement direction is largely changed is found, the group  
10 being divided in a different group.

11 ~~Further, based on the arrangement direction of the~~  
12 distance data of the overall groups, i.e., the gradient with  
13 respect to the Z-axis, the groups are classified into solid object  
14 groups or side wall groups. For the solid object groups,  
15 parameters such as a mean distance, X coordinates of the left  
16 and right ends and the like are calculated from the distance data  
17 of the group. Further, for the side wall groups, parameters such  
18 as the arrangement direction (gradient with respect to the Z-axis),  
19 the positions of the forward and backward ends in terms of Z-X  
20 coordinates and the like are calculated. Thus, the front end,  
21 the side surface and the rear end of a solid object and the  
22 structure such as a guardrail are detected as the side wall  
23 ~~arranged along the road.~~

24 With respect to the generation of distance image, the  
25 process of detecting the configuration of roads from the distance  
26 image and the process of the judgment of collision or contact  
27 with obstacles, details of which are described in Japanese Patent  
28 Application Laid-open No. Toku-Kai-Hei 5-265547 and No.

1 Toku-Kai-Hei 6-266828 both of which have been proposed by the  
2 applicant of the present invention.

3 The present invention is characterized in that even  
4 when the road is curved, the wall surface can be recognized up  
5 to the far distance along the curved road. The process in the  
6 microprocessor 30b will be described according to the flowcharts  
7 shown in Fig. 3 through Fig. 8.

8 ~~The programs shown in Figs 3 through 5 are ones for~~  
9 classifying the solid object group and the side wall group by  
10 processing the distance data obtained from the distance image.  
11 First, at a step S101, the distance image is divided into  
12 lattice-like strips having a given interval (for example 8 to  
13 20 picture elements) and at S102 data of a solid object are  
14 extracted for every strip and the data of the first strip are  
15 ~~read to calculate the distance to the object.~~

16 Next, the program goes to S103 where the data of the  
17 first strip are set and at S104 the three-dimensional position  
18 ( $x$ ,  $y$ ,  $z$ ) of the object is obtained according to the aforesaid  
19 equations (1) to (3). Then, the program goes to S105 where the  
20 height  $yr$  of the road surface at the distance  $z$  is calculated  
21 according to the linear equations (7) and (8) expressing the road  
22 configuration. In case where the road configuration can not be  
23 recognized for example on a road having no lane marker, the road  
24 surface being assumed to be in a horizontal relation with the  
25 vehicle 1, the road height is established to be zero for example.

26 Next, the program goes to S106 where the data above  
27 the road surface are extracted as the solid object data based  
28 on the height  $H$  from the road surface which is calculated according

1 to the following equation (9).

2            $H = y - yr$                                  .... (9)

3 In this case, if the height  $H$  of the object is 0.1 meters or smaller,  
4 since the object of this size is supposed to be a lane marker,  
5 a stain or a shadow on the road, the data of the object are  
6 discarded. Similarly, since the object which is located at a  
7 position higher than the self vehicle 1 is supposed to be a bridge  
8 or a signpost, that object is discarded. Thus, only the data of  
9 objects which are estimated to be solid objects on the road are  
10 selected.

11           After that, the program goes to S107 where it is checked  
12 whether or not the data is final one of the strip. If the data  
13 is not final, after the next data is set at S108, the program  
14 returns to S104 and similar processes are repeated to extract  
15 the data above the road surface. Further, when the final data  
16 of the strip are finished to be processed, the program goes from  
17 S107 to S109 wherein a histogram is prepared. The histogram is  
18 composed of a number of data contained within a predetermined  
19 interval of the distance  $z$  which is aligned on the lateral axis.

20           At the next step S110, if there is an interval in which  
21 the frequency (number of data) is above a threshold value and  
22 further indicates a maximum value, it is judged that a solid object  
23 exists within that interval and the distance to the object is  
24 detected. Thus prepared histogram also contains data erroneously  
25 detected and therefore some data appear in the position where  
26 no object exists. However, it should be noted that if there is  
27 an object having some degrees of size in a position, the frequency  
28 at the position shows a relatively large value and if there is

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1 no object, the frequency is relatively small.  
2 Accordingly, it is permissible to judge that if the  
3 frequency of the histogram exceeds a predetermined threshold  
4 value and besides shows a maximum value in an interval, an object  
5 exists in the interval and that if the maximum value of the  
6 frequency is below the threshold value, no object exists. Even  
7 in case where some amount of noises are included in the image  
8 data, it is possible to detect an object with minimum effect of  
9 noises.

10 After that, the program goes from S111 to S112 where  
11 it is checked whether or not the process has reached a final strip.  
12 If it is judged that the process has not yet reached a final strip,  
13 the program returns to S103 and similar processes are repeated.  
14 When the process reaches the final strip, the program goes from  
15 S112 to S114.

16 Fig. 11 is a view showing the position of solid objects  
17 detected for each strip from the original image. The distance  
18 data of these solid objects are classified into groups having  
19 a close distance with each other by the processes executed at  
20 the steps S114 to S120. The grouping will be performed as follows.  
21 In these processes, the detected distances of the solid objects  
22 in respective strips are investigated. If the difference of the  
23 detected distances to the solid objects between adjacent strips  
24 is smaller than a threshold value, these objects are deemed to  
25 be the same objects and on the other hand, if that difference  
26 exceeds the threshold value, those objects are regarded as  
27 different objects.

28 Specifically, at S114, the first strip (for example,

1 a strip of the left end) is investigated and if a solid object  
2 is detected therein, the distance data are read and this strip  
3 R1 is classified into a group G1 having a distance Z1. Next, the  
4 program goes to S115 where the right adjacent strip R2 is  
5 investigated. If no solid object is detected in the strip R2,  
6 it is judged that the group G1 exists within the strip R1 or in  
7 the neighborhood thereof and the distance is Z1. On the other  
8 hand, if a solid object is detected in the strip R2 and the distance  
9 to the object is Z2, the distance Z1 of the strip R1 is compared  
10 with the distance Z2 of the strip R2.

11 After that, the program goes to S116 where it is judged  
12 whether or not the difference between the distances Z1 and Z2  
13 is smaller than a threshold value and if the difference is smaller  
14 than the threshold value and is close to each other, it is judged  
15 at S117 that the solid object detected in the strip R2 belongs  
16 to the same group G1 to label as such and then the program goes  
17 to S119. At this moment, the distance to the object is established  
18 to be a mean value of Z1 and Z2.

19 On the other hand, in case where the difference of the  
20 distances Z1 and Z2 exceeds the threshold value, the program goes  
21 from S116 to S118 in which, judging that the solid object detected  
22 in the strip R2 does not belongs to the group G1, the solid object  
23 is labeled as belonging to a new group G2 having a distance Z2  
24 and then goes to S119.

25 At S119, it is investigated whether or not the process  
26 has reached a final strip and if not, after the distance of the  
27 next strip is read at S120, the program returns to S115 and further  
28 the right adjacent strip is investigated. If the process has

1 reached the final strip, the program goes from S119 to S121.

2           The following case should be noted. Assuming the  
3 situation where a vehicle parks beside a guardrail, there is a  
4 possibility that the distance data of the guardrail are deemed  
5 to belong to the same group as the distance data of the parked  
6 vehicle. In order to avoid this, the arrangement direction of  
7 the distance data is checked on the X-Z plane through the processes  
8 at S121 to S131 to divide the group of the arrangement direction  
9 into a portion in parallel with Z-axis and a portion in parallel  
10 with X-axis.

11           That is, at S121 the data of the first group are read  
12 and at S122 the arrangement direction of the data of the respective  
13 strips is calculated. Further, at S123 these strips are labeled  
14 as "object" or "side wall", respectively. Specifically, first  
15 two points on the X-Z plane are picked up from the data of the  
16 first group. One point ( $x_1, z_1$ ) is a middle point of a strip  $K_1$   
17 at the left end of the first group and the other point ( $x_p, z_p$ )  
18 is a middle point of a strip far away from the left end strip  
19  $K_1$  by an interval of  $N$  strips in the right hand direction. Then,  
20 a line connecting these two points is drawn on the X-Z plane and  
21 a gradient  $A_1$  of the line is calculated. When the gradient  $A_1$   
22 is compared with a prescribed value, for example 45 degrees, if  
23 the gradient  $A_1$  is larger than the value, the strip  $K_1$  is labeled  
24 as "side wall" and if the gradient  $A_1$  is smaller than the value,  
25 the strip  $K_1$  is labeled as "object".

26           The interval  $N$  between strips is preferably  $N = 2$  to  
27          4. The reason is that  $N = 1$ , namely, an adjacent strip may produce  
28 fluctuations in the arrangement direction of the data due to the

1 ~~dispersion of detected distance and as a result it becomes~~  
2 ~~difficult to make discrimination between "sidewall" and "object".~~  
3 Therefore, it is suitable to use not an adjacent strip, but a  
4 strip a little distant. Hereinafter, the labeling of "side wall"  
5 or "object" is performed successively from the left end strip  
6 up to the strip apart by N strips on the left side of the right  
7 end strip.

8 ~~When the labeling is accomplished for each strip of~~  
9 the group, the program goes from S123 to S124 where the label  
10 of the left end strip is read and at the next step S125, the label  
11 of the right adjacent strip is read. Then, it is investigated  
12 whether or not the label of the left end strip is different from  
13 that of the right adjacent strip. As a result, if the label of  
14 the left end strip is the same as that of the right adjacent strip,  
15 the program skips to S128 and if different, the program steps  
16 to S127 where the strip labeled "side wall" and the strip labeled  
17 "object" are divided into different groups respectively. The  
18 division of the group is performed at the position apart by  $N/2$   
19 strip on the right side of the position where the label changes  
20 ~~from "side wall" to "object" and vice versa.~~

21 In this case, to avoid the situation where the label  
22 itself is erroneously labeled due to the dispersion of distance  
23 data, the division is performed only when more than three same  
24 labels are successive.

25 At S128, it is checked whether or not the process comes  
26 to the final strip and if not, after reading the label of the  
27 next strip at S129, the program returns to S125 and hereinafter  
28 similar processes are repeated. When the process comes to the

1 final strip. The program goes from S128 to S130 where it is  
2 investigated whether or not the process reaches the final group.  
3 When the process does not yet reach the final group, the data  
4 of the next group are read and hereinafter the same processes  
5 are carried out repeatedly. When the process reaches the final  
6 group, the division of the groups is completed and the program  
7 goes from S130 to S132.

8 ~~The following steps S132 to S137 are of processes in~~  
9 which further classifications of "side wall" or "object" are  
10 carried out to raise the accuracy of the classification performed  
11 at S127. After the data of the first group are read at S132, at  
12 S133 approximate straight lines are obtained from the positions  
13 ( $X_i, Z_i$ ) within the group according to the Hough transformation  
14 or the linear square method to calculate a gradient overall the  
15 group.

16 ~~Then, the program goes to S134 where the group is~~  
17 reorganized such that the group having a gradient inclined toward  
18 X-axis is classified into the "object" group and the group having  
19 a gradient inclined toward Z-axis is classified into the "side  
20 wall" group. Further, at S135, miscellaneous parameters of the  
21 group are calculated. With respect to the group classified  
22 "object", these parameters include an average distance which is  
23 calculated from the distance data within the group, X-coordinates  
24 at the left and right ends of the group and the like and with  
25 respect to the group classified "side wall", those parameters  
26 include an arrangement direction of the data (gradient with  
27 respect to Z-axis), Z, X coordinates of the front and rear ends  
28 of the group and the like. In this embodiment, in order to raise

1 the accuracy of classification, the group is reclassified  
2 according to the calculated gradient of the overall group, however  
3 this reclassification may be omitted.

4 Further, the program goes from S135 to S136 where it  
5 is judged whether or not the process has reached the final group.  
6 If it is not the final group, the program goes back to S137 in  
7 which the data of the next group are read and returns to S133  
8 to repeat the same processes. When the process has reached the  
9 final group, the program leaves the routine.

10 Fig. 12 shows a result of the detection of the side  
11 wall. When the data of the groups are illustrated on the X-Z plane,  
12 as shown in Fig. 13, they are recognized as "side wall" groups.  
13 In this case, portions along a curved road are not recognized.  
14 The program shown in Fig. 6 is for recognizing the wall surface  
15 along the curved road using the data of the "side wall" group  
16 obtained by the program described before.

17 First, at S201, groups estimated to be a wall surface  
18 are selected from the groups classified "side wall" and at the  
19 steps after S202, a wall surface is searched based on the data  
20 of the "side wall" groups using the following wall surface model.

21 The wall surface model is shown in Fig. 14, in which  
22 the wall surfaces are expressed as border lines connecting between  
23 nodes provided at a specified interval within a given range. For  
24 example, the border line is constituted by 41 nodes arranged at  
25 an interval of 2 meters within an range from 10 to 90 meters ahead  
26 of the self vehicle. Respective nodes have successive reference  
27 numbers starting from the self vehicle side. The Z-coordinates  
28 of the respective nodes are fixed with respect to the vehicle

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1 position and X-coordinates thereof are determined according  
2 to the procedure which will be described hereinafter.

3 At S202, a node  $N_s$  corresponding to an end point on the  
4 vehicle side of the selected side wall group is established based  
5 on the Z-coordinate of the end point and the X-coordinate of the  
6 node  $N_s$  is established being adjusted to the X-coordinate of the  
7 end point. Next, the program goes to S203 where the next node  
8  $N_{s+1}$  is established in the direction of the gradient of the side  
9 wall group. Next, when the node  $N_{s+1}$  ( $i \geq 2$ ) is determined, its  
10 direction is established along a direction of the second previous  
11 node.

12 Then, the program goes to S204 where, as shown in Fig.  
13 15, the position of the wall surface is searched by a so-called  
14 "pattern matching" within a specified searching range to extract  
15 a solid object  $P_i$  for every strip within the searching range. For  
16 example, the searching range in the X-axis direction has  $\pm 3$  to  
17 5 meters in the X-axis direction and  $\pm 1$  meter in the Y-axis  
18 direction with its center placed at a coordinate  $(X_{ns+1}, Z_{ns+1})$  of  
19 the node  $N_{s+1}$  established at S203.

20 The matching of the wall surface pattern is performed  
21 to the solid object  $P_i$  within the searching range. Fig. 16 shows  
22 an example of the wall surface pattern (weight coefficient  
23 pattern) used for the pattern matching. The wall surface pattern  
24 shown in Fig. 16 is a pattern for the wall surface on the left  
25 side and a symmetric pattern to this pattern is used for the wall  
26 surface on the right side. The lateral axis of this wall surface  
27 pattern coincides with the distance in the X-axis direction and  
28 the longitudinal axis indicates a weight coefficient. A maximum

1 point of a degree of coincidence is searched while the central  
2 point of the wall surface pattern is shifted towards the X-axis.  
3 Specifically, as shown in Fig. 17, a weight  $W_i$  is obtained with  
4 respect to the deviation of the solid object  $P_i$  in the X-axis  
5 direction from the central point of the wall surface pattern to  
6 calculate the sum of the weight  $W_i$  as a degree of coincidence  $F$ .  
7 Further, when the degree of coincidence  $F$  becomes maximum, the  
8 position of the central point of the wall surface pattern is  
9 recognized as a wall surface. When the maximum value of the degree  
10 of coincidence  $F$  is smaller than a threshold value, it is judged  
11 that there is no wall surface.

12 When the process of the step S204 finishes, the program  
13 goes to S205 at which a X-coordinate  $X_{pw}$  of the central point of  
14 the wall surface pattern at the maximum point of the degree of  
15 coincidence  $F$ , is established as a X-coordinate of the wall  
16 surface pattern corresponding to the node  $N_{s+1}$ .

17 Then, the program goes to S206 where it is checked  
18 whether or not the node is the last one of the side wall group  
19 selected and if it is not the last node, the program goes back  
20 to S203 and the same processes are repeated. When the process  
21 reaches the last node, the program steps to S207 where the node  
22 having the smallest reference number (the node nearest to the  
23 self vehicle) and the node having the largest reference number  
24 (the node furthermost from the self vehicle), are searched  
25 respectively and leaves the routine after denoting them as a start  
26 point  $N_s$  and an end point  $N_e$ , respectively.

27 After this program is carried out on the side wall  
28 groups on the left side, it is carried out on the side wall groups

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1 on the right side. In the example shown in Fig. 14, the wall surface  
2 from the 9th node to the 26th node is detected on the right side  
3 of the self vehicle and the 9th node is denoted as the start point  
4  $N_s$  and the 26th node is denoted as the end point  $N_e$ . These nodes  
5 are used for later processes as effective nodes.

6 Thus processed position of the wall surface is further  
7 corrected by a program shown in Fig. 7 and Fig. 8 using new data  
8 obtained from programs shown in Fig. 3 through Fig. 5.

9 The programs shown in Fig. 7 and Fig. 8 is a program  
10 for correcting the wall surface. At S301, it is investigated  
11 whether or not the start point  $N_s$  of the effective nodes is larger  
12 than the first node  $N_1$  of the wall surface model. When  $N_s = N_1$ ,  
13 the wall surface has been already detected up to the first node  
14  $N_1$ , the program skips to S306. When  $N_s > N_1$ , the program goes to  
15 S302 where the previous node  $N_{s-i}$  ( $i = 1, 2, 3$  etc.) is established.  
16 Then, at S303 the wall surface pattern is searched and at S304  
17 the X-coordinate of the wall surface is determined based on the  
18 result of searching.

19 Next, the program goes from S304 to S305 where it is  
20 investigated whether or not the process has reached the first  
21 node. If not yet reached the first node  $N_1$ , the steps S302 to S304  
22 are repeated to continue the searching of the wall surface  
23 position up to the node  $N_1$ . When the processes up to the first  
24 node  $N_1$  are finished, the program goes to S306 where it is checked  
25 whether or not the end point  $N_e$  of the effective nodes is smaller  
26 than the last node  $N_{se}$  of the wall surface model (for example,  
27 node  $N_{41}$  in case of the wall surface model constituted of 41 nodes).

28 As a result of this, when  $N_e = N_{se}$ , that is, the wall

1 surface has been already detected up to the last node, the program  
2 skips from S306 to S311. When  $N_e < N_{se}$ , the program goes from S306  
3 to S307 where the node  $N_{e+1}$  after the end point  $N_e$  is successively  
4 established and further at S308 the pattern matching of the wall  
5 surface is performed. According to the result of the pattern  
6 matching, at S309 the X-coordinate of the wall surface is  
7 determined and then at S310 it is checked whether or not the process  
8 has reached the last node  $N_{se}$ . The matching of the wall surface  
9 position is continued until the last node  $N_{se}$  and when the processes  
10 up to the last  $N_{se}$  is finished, the program goes to S311.

11 These processes of establishing the nodes, the matching  
12 of the wall surface pattern and the determination of the X-  
13 coordinate at the steps S302 to S304 and the steps S307 to S309,  
14 are the same as the processes at the steps S203, 204 and S205  
15 in the aforementioned program of the wall surface detecting  
16 process.

17 The processes after S311 are for correcting the  
18 position (X-coordinate) of respective nodes from the first node  
19  $N_1$  to the last node  $N_{se}$ . First, at S311 the data of the first node  
20  $N_1$  is set and the program goes to S312. The processes from S312  
21 to S321 are repeatedly carried out by successively setting the  
22 data of the next node.

23 At S312, the wall surface at the node  $N_1$  is searched  
24 and at S313 it is checked whether or not the wall surface is  
25 detected by the pattern matching. If it is judged that the wall  
26 surface is detected, the program goes from S313 to S314 where  
27 it is investigated whether or not the difference between the  
28 position  $X_{pw}$  of the wall surface and the position  $X_{ni}$  of the node

1 is within a prescribed amount, for example,  $\pm 1$  meter. If the  
2 difference is within the value, the program goes to S315 where  
3 the node is moved to the position of the wall surface ( $X_{ni} \leftarrow X_{pw}$ )  
4 and if the difference is out of the value, the program goes to  
5 S316 where the node is moved toward the wall surface by a specified  
6 amount, for example,  $\pm 0.3$  meters ( $X_{ni} \leftarrow X_{ni} \pm 0.3$  meters).

7 On the other hand, when the wall surface is not detected  
8 by the pattern matching, the program diverges from S313 to S317  
9 where the number  $C_0$  of the data  $X_{pi}$  of the solid objects located  
10 on the left side of the node  $X_{ni}$  ( $X_{ni} < X_{pi}$ ) and the number  $C_1$  of  
11 the data  $X_{pi}$  of the solid objects located on the right side of  
12 the node  $X_{ni}$  ( $X_{ni} > X_{pi}$ ), are counted respectively. Then, at S318  
13 the node is moved towards the side having more data of solid objects  
14 by a specified amount, for example 0.8 meters ( $X_{ni} \leftarrow X_{ni} \pm 0.8$   
15 meters).

16 Thus, in case where there is no wall surface pattern  
17 detected near the node, the position of the node can be neared  
18 in the direction where the wall surface likely exists even when  
19 the node is largely apart from the wall surface.

20 When the position of the node is moved through either  
21 step of S315, S316 and S318, the program goes to S319 where a  
22 position  $X_c$  of a mid-point of a straight line connecting a node  
23  $N_{i+1}$  (adjacent node on far side) and a node  $N_{i-1}$  (adjacent node on  
24 near side) is obtained and then goes to S320 where, as shown in  
25 Fig. 18, the node  $N_i$  is moved toward the mid-point  $X_c$  just like  
26 in a manner that the mid-point  $X_c$  attracts the node  $N_i$  by a spring  
27 force. The amount of the movement should be retained as much as  
28 1/2 to 1/5 of the length between the node  $N_i$  and the mid-point

1 X<sub>c</sub>.

2 That is, the wall surface detected by the pattern  
3 matching generally contains irregularity due to the effect of  
4 the dispersion of data but a real guardrail or real side wall,  
5 in most case, is smoothly curved along a road. The process at  
6 S320 is a means for obtaining a smooth curve by applying a spring  
7 operation as described above. As a conventional method of  
8 smoothing the configuration composed of nodes, a least square  
9 method is well known, however the aforesaid method using a  
10 spring operation is more advantageous in calculation speeds than  
11 such a conventional method.

12 After that, the program goes to S321 where it is  
13 investigated whether or not the process has reached the last node  
14 N<sub>se</sub>. and if it has not reached the last node point, the program  
15 returns to S321 after setting the data of the next node at S322  
16 and the same processes are repeated. When the process at the last  
17 node N<sub>se</sub> is finished, the program goes from S321 to S323 where  
18 it is checked whether or not the amount of the movement comes  
19 within a threshold value (for example,  $\pm 0.1$  meters) for all of  
20 the points.

21 Further, if a node exceeding the threshold value is  
22 found, the program goes back to S311 and thereafter the correcting  
23 processes are repeated for all nodes from the first to the last.  
24 When the amount of the movement for all node points comes within  
25 the threshold value, the start point N<sub>s</sub> and the end point N<sub>e</sub> within  
26 the detecting range of the nodes are obtained and the program  
27 leaves the routine. Through thus constituted program, erroneously  
28 detected data and others are corrected during repeated processing

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1 and as a result the configuration of the wall similar to the actual  
2 wall surface is obtained. After the program is finished to be  
3 carried out with respect to the side wall groups on the left side,  
4 the program is carried out with respect to those on the right  
5 side.

6 Fig. 19 shows a result of the detection of the wall  
7 surface located from near to far along a curved road on the basis  
8 of the original image shown in Fig. 9 and the corrected wall surface  
9 model expressed on a X-Z plane is shown in Fig. 20. Comparing  
10 this wall surface model with the one detected in the form of  
11 straight lines as shown in Fig. 13, it is understood that the  
12 wall surface can be recognized up to far.

13 This wall surface model can be applied not only to a  
14 guardrail but also to a line of trees, walls of houses, an array  
15 of parked cars and other solid objects lined along a road and  
16 these objects can be detected as a series of wall surfaces.  
17 Therefore, it is possible to recognize the configuration of a  
18 road even in case of a road whose lane markers can not be recognized,  
19 for example a snow-covered road.

20 While the presently preferred embodiment of the present  
21 invention has been shown and described, it is to be understood  
22 that this disclosure is for the purpose of illustration and that  
23 various changes and modifications may be made without departing  
24 from the scope of the invention as set forth in the appended claim.